

CLEVER – A THREE WHEEL VEHICLE WITH A PASSIVE SAFETY COMPARABLE TO CONVENTIONAL CARS

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ABSTRACT

The alternative vehicle called CLEVER (Compact Low Emission Vehicle for Urban Transport) is conceived as a small, three-wheel vehicle with minimal demands on urban space, both in terms of traffic and parking. Furthermore, energy consumption, exhaust and noise emissions are low. CLEVER is funded by the European Commission with the Growth Programme of the Fifth Framework Programme.

The CLEVER project task is to find solutions for the challenge of increasing mobility by developing a new type of a small vehicle, which could be an alternative to traditional cars.

As a result, a vehicle was designed that is classified as a three-wheeler, according to European Union directive 2002/24/EC (class of motorcycles).

The main characteristics are:

- three-wheel vehicle for two occupants with a tilting, enclosed body
- dimensions: length 3.0 m; width 1.0 m; height 1.4 m
- use of a natural gas engine
- energy storage by using specially designed removable gas cylinders

Furthermore, the requirements define that passive safety standards must be comparable to the safety level of conventional cars. In addition, the CLEVER vehicle has to meet all relevant European legal requirements.

In order to meet these requirements, the vehicle's frame structure must be very stiff and a special restraint system had to be designed. The restraint system consists of state-of-the-art components and specially designed components, which are adapted to CLEVER's requirements.

This paper includes a description of the CLEVER safety concept, i.e. of the components' character-

istics, as well as information concerning the results generated by the numerical simulation.

INTRODUCTION

With the constantly increasing need for mobility, particularly in urban areas, various problems arise including the urban space and energy consumption. In addition, exhaust and noise emissions have to be mentioned. In order to be able to satisfy the mobility needs in the future, new solutions are required. Therefore, it is necessary to develop new concepts for individual urban transport to close the gap between conventional individual transport and public transport. Due to the increasing readiness of customers to buy a second or third vehicle, there will be a market for new, innovative vehicles for urban transport.

The project aims at improving urban transport, whilst minimising of negative environmental impacts caused by increased mobility. Within the CLEVER project, various requirements are recognised (e.g. customer requirements, environmental requirements, safety requirements etc.).

Different European companies and research institutes (e.g. BMW, TAKATA-PETRI, Technical University Berlin) are working together to meet the requirements.

Goal of the CLEVER project is to identify general conditions for new mobility concepts, and to realise a vehicle with the following characteristics:

- three-wheel vehicle with minimal requirements on urban space (for 2 occupants)
- environmental friendly, optimised for urban transport
- length = 3.0 m, width = 1.0 m
- natural gas engine
- tilting mechanism

- aluminium Frame
- CO₂ – emissions approx. 50 – 60 g/km in the European car driving cycle
- high level on passive safety comparable to small and micro-cars (checked by a rating-test)



Figure 1. The CLEVER vehicle.



Figure 2. Pictures of a 1:4 model of the CLEVER vehicle.

To meet the defined goals for the safety, the vehicle structure and the restraint system have to be designed and optimised in a special way. TAKATA, as the project partner responsible for the restraint system, will use optimised state-of-the-art components, as well as specially designed components concerning to the occupant body regions, which have a higher injury risk. These body regions were figured out by the accident analysis.

CLEVER ACCIDENT ANALYSIS

The following accident analysis is based on data from the German Federal Accident Statistics (GFAS), the German In-Depth Accident Study (GIDAS) and the National Accident Sampling System (NASS).

Statistic analysis in general

In general, the reporting period was from July 1999 to April 2004 for GIDAS and GFAS. The NASS data analysis describes the statistic period from 1996 to 2002. Additionally, for the period of time between 1985 and 1995, data of 1029 motorcycle accidents and 89 scooter accidents are available.

Because of the special design, the same accident situation as for scooters and motorcycles can be assumed for CLEVER. The driving performance and the application areas, which are mostly cities, is mostly similar with scooters and motorcycles.

Because of the fact that for CLEVER a restraint system will be used, which is comparable with state-of-the-art restraint systems for cars, the occupant kinematics during accidents and the injured body regions could be more similar to car accidents than to scooter or motorcycle accidents.

That is why, different accident data (for cars, motorcycles and scooters) were analysed.

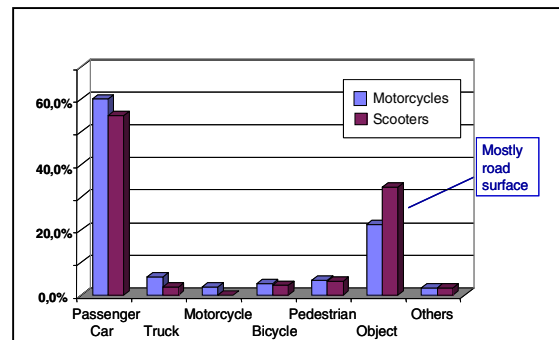


Figure 3. Collision opponents for motorcycles and scooters. [1]

Figure 3 shows the collision opponents of motorcycles and scooters. The main opponents are passenger cars, followed by the collisions of two wheelers with objects, mostly the road surface.

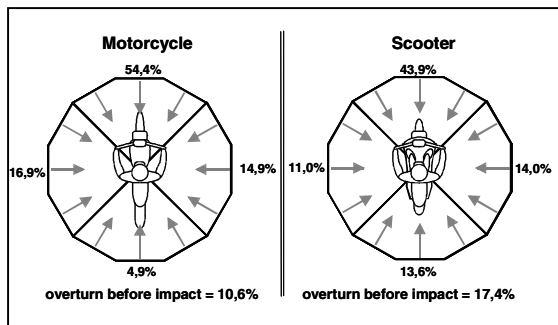


Figure 4. Directions of impact for motorcycles and scooters. [1]

The main impact directions for motorcycles and scooters are the frontal directions (figure 4), followed by side impact and overturn. Similar impact directions can be assumed for CLEVER because of similar vehicle width.

Accident analysis for the driver

The following figure shows the body regions, which are affected in accidents with a two wheel vehicle.

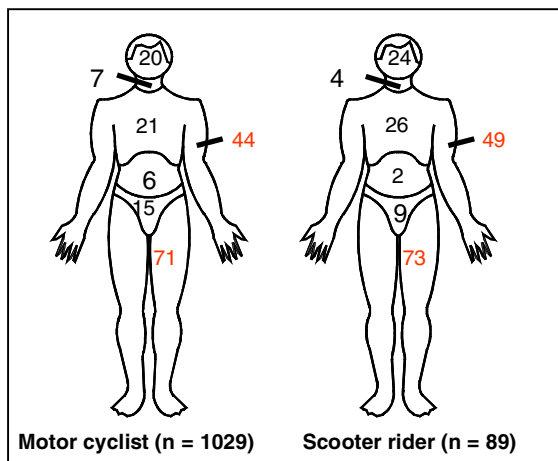


Figure 5. Affected body regions of persons involved in two-wheel vehicle accidents. [1]

As result, the body regions (most injured) are arms and legs. The most fatal or severe injuries result from head injuries, followed by thorax injuries. It has to be stated that in 95 % of all cases, helmets were used.

These data only show the figures for riders, due to the fact that the figures for passengers are extremely low.

The closing speed in accidents is far lower for scooters than for motorcycles. More than 95 % of all registered accidents are covered with a closing speed of 50 kph (figure 6). In addition, the closing speed of accidents with the “Smart” (built by DaimlerChrysler for the European market) was figured out and evaluated. These data are also

available in the GIDAS database. This closing speed is nearly similar to the closing speed of scooters. The low number of 28 reported accidents with an involved “Smart” is not very representative. But it gives an idea about the tendency for small and micro car accidents.

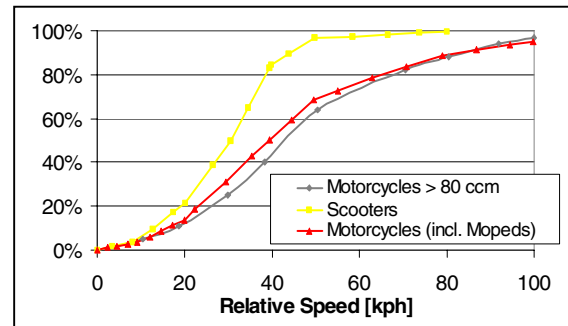


Figure 6. Accident closing speed of two-wheelers. [1]

The concept of the BMW C1, a two-wheel vehicle equipped with seat belts, load limiter and energy absorbing elements, is partly similar to the CEVER concept. In several EU member states, it is allowed to drive the C1 without wearing a helmet.

The main results of accident analysis by BMW are illustrated with two examples, which describe the real world accident performance of the C1.



Figure 7: The BMW C1. [2]

In frontal collision with a velocity of about 50 kph of the C1, and approximately 20 kph of the collision opponent (car), the belted driver (without helmet protection) had a AIS 1 injury-severity. Furthermore, a few injuries like cuts and contusions at the upper and lower extremities were reported.

In a side collision between a C1 and a middle class car, the belted C1 driver had lacerations and contusions of his left leg and abrasions at his left forearm and hand.

These results should be typical for the C1 accident situation taking account to the low number of reported accidents. [2]

It seems that the most endangered body parts of the C1 driver are the extremities.

Passenger statistic analysis

In order to determine the most affected body regions of passengers, a statistic analysis of the accidents with car occupants in the second or third row will be used. The database for this analysis includes traffic fatalities, sampled by GIDAS and NASS.

The GIDAS database gives the information that for a number of 347 traffic fatalities, 195 of the occupants were car passengers. Out of these 195 passengers, 22 did not use the first row and 12 of them were seated in the second row during a frontal crash.

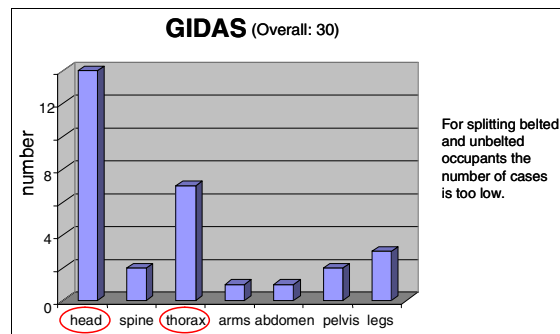


Figure 8. Passenger injured body regions from the database GIDAS. [3]

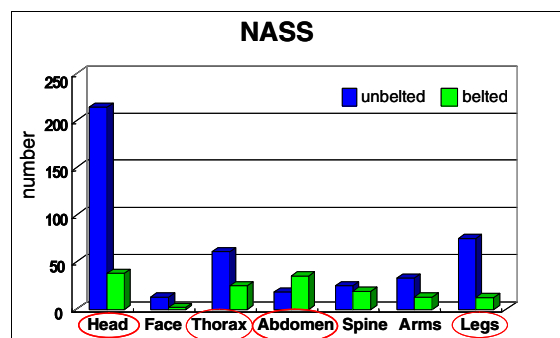


Figure 9. Passenger injured body regions from the database NASS. [4]

These figures show that the most affected body regions with AIS3+ injuries are the head and thorax of passengers. This applies to Europe as well as to the US.

Other results of the investigation for passengers are that the occupant position is quite regular. The closing speed for these accidents is between 20 kph and 60 kph.

The reasons for the accidents were mostly DWI (driving while intoxicated) and speed. About 50 %

of the accidents occur without involving other road users.

Result of the accident investigation

As result of this accident investigation, the following scenarios must be in the centre of frontal restraint system development.

Main collision opponents will be conventional cars. The main impact type will be frontal impact. Another important accident type is single collision by hitting an object.

As to the injuries regarding body regions, the frequency of head, thorax and pelvis injuries can be reduced significantly by use of conventional restraint systems.

The open passenger compartment of the BMW C1 does not give enough protection for the upper and lower extremities of the occupants. The absolute number could be reduced, compared to the injury figures for the upper and lower extremities for riders of two-wheelers.

CLEVER SAFETY REQUIREMENTS

The main safety requirements for the CLEVER vehicle are listed below:

- Meeting all legal requirements
- No obligation to wear a helmet (similar to the BMW C1)
- High level of passive safety comparable to the level of conventional cars

Legal Requirements

For a three-wheel vehicle like CLEVER, no legal requirements exist concerning passive safety for the approval of motorcycles. To attain an operating license, the European regulation 97/24/EG has to be met. This regulation specifies constructive characteristics of vehicle parts, windshields and the seat belts with their connections to the vehicle, if included.

The obligation to use crash helmets is compulsory (in European countries) for riders and passengers of motorcycles without a full-lining. However, different exemptions exist in EU member states.

For Germany, exemptions are defined by the vehicle type approval or by legislation, like the C1. For example, the German law allows for two-wheel vehicles to be ridden without wearing a helmet, if the following requirements are fulfilled:

- The belt system must be state of the art and comply with Directive 97/24/EC.

- A light signal for a clear warning, if the rider is not wearing a belt, is required, as per Directive 78/316/EEC.
- The requirements for windows must be fulfilled, amongst others the minimum radii have to be complied with European Union Directive 97/24/EC.
- Crash tests against a motorcar have to be performed (according to ISO 13232, which defines relevant impact scenarios for two-wheelers) – the values for the HPC criterion have to be lower than 1000
- Lateral fall tests without head contact to the road surface and roof indentation tests (FMVSS 216) have to be fulfilled.

On the basis of this directive, the exemption to wear a helmet applies to other European countries. [2]

Additional safety requirements for CLEVER

However, to meet the requirements for accepting CLEVER for the ACEA CO₂-Agreement [5], the vehicle “should demonstrate passive and active safety appropriated to it’s intent to use”. To be able to assess these requirements, the CLEVER consortium defined a test procedure called “CLEVER-CAP”. This procedure should allow comparing the passive safety level of CLEVER to conventional cars. Therefore, it is reasonable to use similar or nearly similar test procedures as in consumer rating programmes.

The most important consumer test for Europe is the EuroNCAP, while the US-NCAP is the state-of-the-art consumer test for the United States. CLEVER is mainly designed to cope with European requirements. Therefore, the EuroNCAP test procedure should be favoured.

However, due special design properties of CLEVER, it does not seem to be realistic to follow the test procedure completely.

Frontal Impact

EuroNCAP defined a 40%-offset crash configuration against a deformable barrier for the frontal impact test. Because of the shape and width of the CLEVER vehicle, an offset crash seems not to be a suitable test to simulate real-world accidents. Data analysis revealed that frontal impacts were the main type of impacts for motorcycles. In addition, it is nearly impossible to conduct a 40%-offset crash with CLEVER, because 40 % of the front structure width is about 100 mm and the vehicle width is increasing from front to rear. Vehicle motions following a crash would not take place in a reproducible manner.

As a result of these conditions, a crash test configuration with impacting a rigid wall without an offset barrier is usable and should give a realistic output concerning to the anticipated accident situation.

For frontal impact, the test configuration of the US-NCAP is useful. This means a frontal impact with 56 kph against the rigid wall. For comparing the CLEVER safety level with the safety level of European conventional cars, the EuroNCAP Star-rating is used.

In addition, chest acceleration will be measured. This allows a verification of the test results according to the US-NCAP rating. It seems possible to meet US-NCAP rating without major problems.

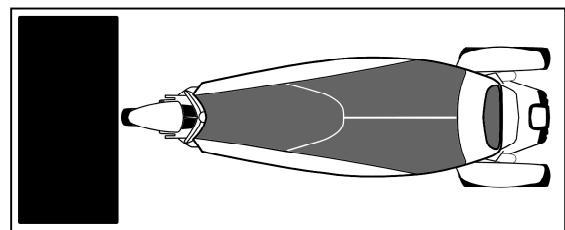


Figure 10. CLEVER frontal test configuration. [1]

This paper focuses mainly on the frontal impact, because this configuration was the most challenging one.

Side Impact

For lateral impact testing, the EuroNCAP is the most suitable test procedure. Therefore, this procedure is selected for CLEVER.

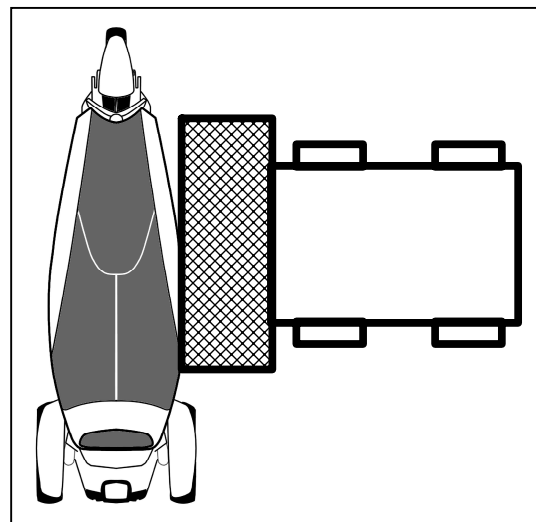


Figure 11. CLEVER side test configuration. [1]

Roll-over

For CLEVER, the impact after an overturn is likely the most realistic scenario for the roll-over impact.

The safety cell will be tested by a static structure test procedure. The safety cell should resist a static force impact of about 22,2 kN.

Pedestrian Safety

The pedestrian safety level of the CLEVER vehicle will be checked by numerical simulation. Frontal impact to pedestrians with a velocity of 40 kph will be simulated. The assessment of criteria will comprise the mechanical loads to head, neck, and legs.

CLEVER VEHICLE STRUCTURE AND CRASH PULSE

The level of passive safety depends on different parameters. One important parameter is the characteristic of the crash pulse, mainly influenced by the crash velocity and the vehicle's structure.

In conventional cars, the crash structure influencing the accident performance is composed of a bumper, crash boxes and long members. Due to the CLEVER design with one wheel in the front, this conventional way of energy absorption is not possible. Therefore, a new approach was necessary. Special effort was needed to avoid any intrusion into the cabin, as the driver's feet are located directly behind the front wheel.

The crash structure of the CLEVER vehicle consists of the front wheel, the swing arms (front wheel suspension) and special designed crash elements. While conventional car wheels are stiff, motorcycle wheels normally brake in accidents. The CLEVER front wheel is designed to deform under crash loads. This is important to use as much as possible deformation length without injuring the legs of the driver on the one hand and for compatibility reasons in a side impact, when CLEVER hits a conventional car, on the other hand.

The stiffness of the swing arms is quite high, resulting in small deformations of this part. However, the swing arms are designed to route the crash forces to the crash elements, which connects the swing arms with the stiff frame. These deformable elements allow the front wheel to move backwards together with the suspension, which absorbs energy. The cabin frame itself offers appropriated stiffness to avoid dangerous intrusions in frontal impacts. The body panels are made of laminated synthetic materials. The influence of the body panels to the crash behaviour should be negligible small.

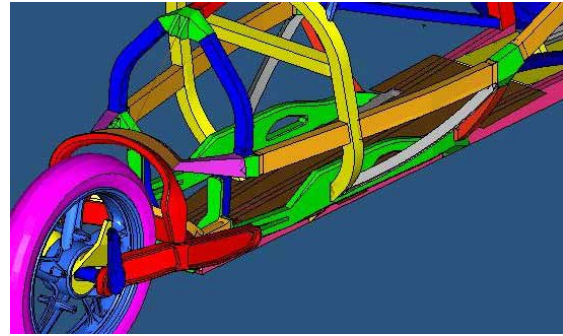


Figure 12. CLEVER – front frame structure.

Based on finite element simulations the above described measures lead to the pulse shown in the following figure.

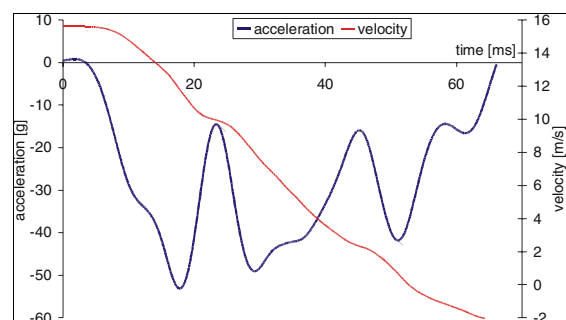


Figure 13. CLEVER crash pulse.

The order of magnitude of these accelerations agrees with the documented test results of micro-cars.

A picture of the expected deformation is shown in figure 14.

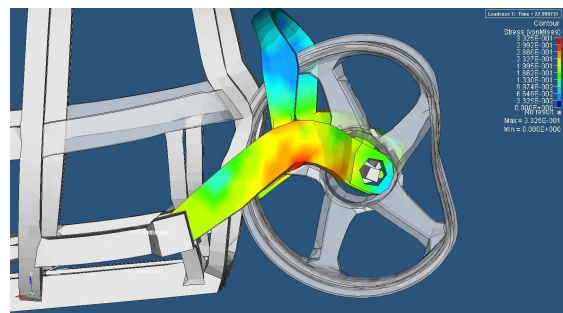


Figure 14. CLEVER deformation characteristic.

Concerning the lateral impact, the introduced cross beams lead to appropriated cabin stiffness. The expected intrusion and intrusion velocity will not exceed 130 mm or 7,8 m/s, respectively figure 15.

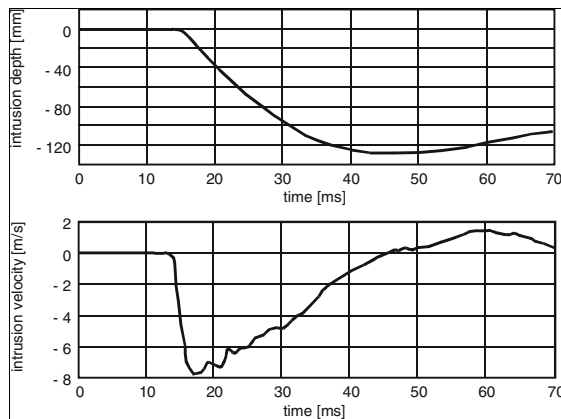


Figure 15. Lateral impact characteristics in 50 kph MDB test.

The deformation of the structure is shown in the figure below.

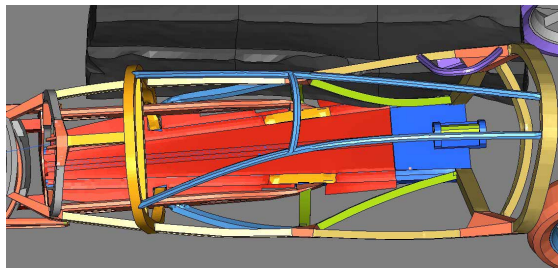


Figure 16. Maximum deformation in EuroNCAP lateral impact.

The special designed rear seat will introduce additional lateral stiffness, which will result in lower intrusion and intrusion velocity.

The knowledge about the structural behaviour of the vehicle allows the design of the restraint system.

CLEVER FRONTAL RESTRAINT SYSTEM

CLEVER's frontal restraint system will be specially designed. The package conditions are not similar to conventional cars.

To reduce the engineering and production costs for CLEVER, standard components for the restraint system were used wherever possible. However, due to the challenging restraint requirements caused by the small vehicle and the high pulse, it was necessary to adopt and modify existing components and design special components for CLEVER.

MADYMO-Simulation of the CLEVER Vehicle

The performance of the restraint system was checked by using numerical simulation tools. Furthermore, the components for the restraint

system were also adjusted by numerical simulation too.

The computer programme MADYMO was chosen for the simulation. With this solver, it is possible to combine the capabilities of multi-body and finite element techniques.

In a first step, a very simple simulation model was built up, which presented the known vehicle characteristic at the beginning of the project. It was used for preliminary investigations. With this model, it was possible to see that the requirements could be met.

When the project progressed, more detailed characteristics for the vehicle were defined. A better simulation model was built. Consequently, more exactly investigations could be carried out. The effect of different components like pretensioner or load limiters, separate or in combination with other components, were analysed. In addition, the safety level for different occupants (5%-HIII, 50%-HIII, 95%-HIII) was checked.

As main output of this development step, the necessity of a combination of driver airbag, pretensioner and load limiter for reaching a three star ranking with the 50%-HIII was shown. For the 5%-HIII and the 95%-HIII, the same configuration of the restraint system will lead to best results.

These investigations started by using a synthetic generated crash-pulse. Within the ongoing development, a more realistic crash pulse (figure 13) generated by the structural simulation was used and, consequently, more realistic results could be generated.

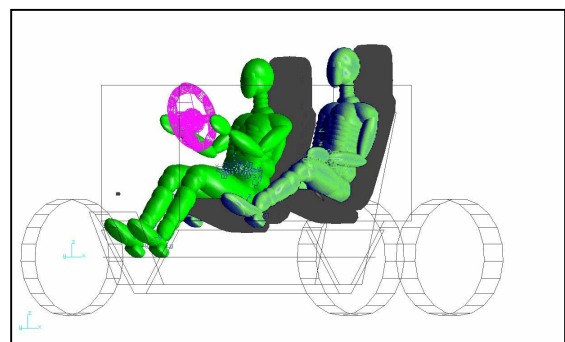


Figure 17. More detailed simulation model.

In the next development step, a final model was built. This model included all defined geometries, shapes, material characteristics and well known, validated components.

This final simulation model was consequently built with multi-body parts (dummy, steering wheel) and finite element parts (seat, airbag, and belt).

The complete results for the driver and passenger will be shown below. Because of the imprecision of

the simulation model, it is nearly impossible (at the moment) to generate realistic results for the lower extremities. For example, the design of the knee contact area of the dashboard and the footrest (with the mounted pedals) is not yet finished. It should be kept in mind that this could influence the overall performance rating compared with the currently existing results based on numerical simulations.

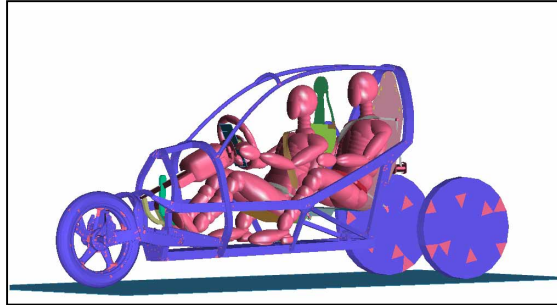



Figure 18. Final CLEVER numerical simulation model.

Driver Restraint System

The current CLEVER results for the driver and the passenger are shown in the following table. The limits are comparable to the CLEVER-CAP limits. For the driver, the difference between a restraint system with deformable steering column and with stiff steering column is additionally shown.

Table 1.
Calculated results for the CLEVER driver

 TAKATA		Limits 50% HIII CLEVER- Requirements 2003	18.02.2005 Driver 50% HIII	18.02.2005 Driver 50% HIII
EuroNCAP -Criteria- 50% HIII			CLEVER-Pure first	CLEVER-Pure first
Simulation	seat rest	-	-	-
	Airbag	-	60 l coated 2 x 30 mm stiff	60 l coated 2 x 30 mm deformable
	AOE Steering column	-	-	-
Head	HIC ₃₅	883	658	412
	HIC ₁₅	-	-	-
	a _{3ms} [g]	83	58	43
	-	-	-	-
Neck	My+ (max. Flexion) [Nm]	-	80	55
	My- (max. Extension) [Nm]	52	14	14
	Fx+/- (max. Shearforce) [kN]	2,7	1,0	0,7
	Fz+ (max. Force) [kN]	3,1	1,3	1,1
	Fz- (max. Force) [kN]	3,1	0,2	0,2
Thorax	a _{3ms} [g]	-	59	58
	a _{max} [g]	-	-	-
	s _{max} [mm]	41	40	39
	VC [m/s]	0,83	0,22	0,22
Pelvis	a _{3ms} [g]	-	92	92
Femur	Fz left [kN]	7,3	5,1	5,1
	Fz right [kN]	7,3	7,1	7,1

The limits, defined by the CLEVER-CAP for the frontal impact, were partially below target. In comparison to the US-NCAP, a three-star rating could be possible.

These results come from a comparison of different components for the driver restraint system by numerical simulation. The most effective system

consists of a deformable steering column, a driver airbag with two chambers, a pretensioner, and a dual stage load limiter. The system is shown in the figure 19.

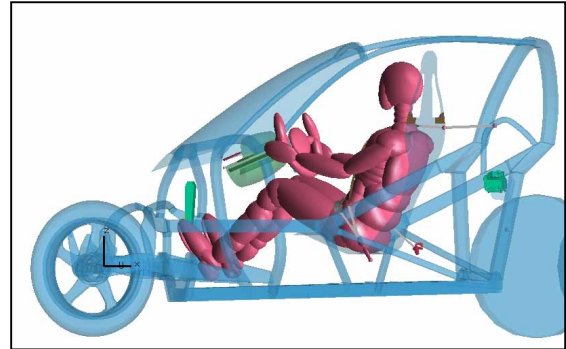


Figure 19. CLEVER driver restraint system.

The steering column is an existing one, used in conventional cars out of the series production.

The difference between restraint systems with a deformable and non-deformable steering column is significant. That is why the decision was made, to include a deformable steering column.

In the following figure, the difference of the energy application of the airbag from a restraint system with deformable and non-deformable steering column is shown. In a restraint system without deformable steering column, the kinetic energy of the head and partly of the thorax will be absorbed by the airbag, and the deformation of the steering wheel. If a deformable steering column is used, the airbag has to absorb about 1/3 less energy. This 1/3 will be absorbed by the deformable steering column. So the diameter of the airbag vents can be increased. That is why the airbag will be much softer. This will result in lower values of the assessment criteria.

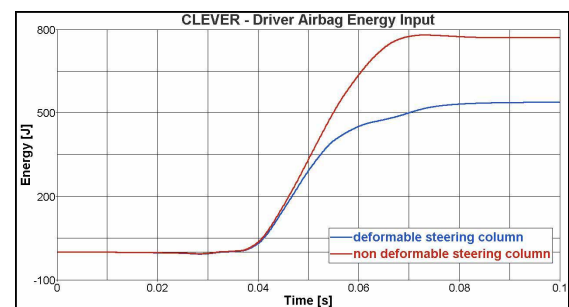


Figure 20. Application of energy by the airbag.

The steering wheel is a modified steering wheel from serial production. Some styling and design modifications will be necessary. The deformation characteristics are well known.

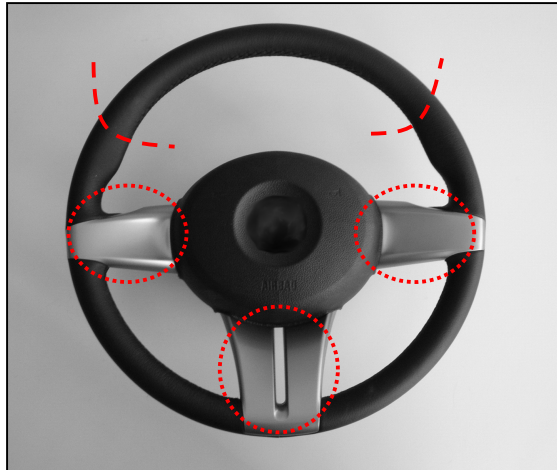


Figure 21. Possible modifications of a series steering wheel for CLEVER.

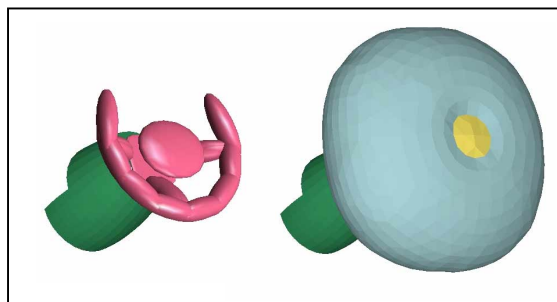


Figure 22. Simulation model of the steering column, steering wheel and driver airbag.

The airbag system is consisting of a dual-stage inflator in combination with a 60 l two-chamber airbag. There are two venting holes with a diameter of about 30 mm each. This provides excellent performance for head protection in combination with lower impact force to the sternum. The positioning of the airbag will be better than with a conventional one chamber airbag.

In the case of a restraint system without driver airbag, the head of the driver would touch the steering wheel. High values for head acceleration and the HIC would follow. To avoid these effects, the decision to use a driver airbag was taken.

The belt system is fitted with a retractor mounted pretensioner. A dual-stage load limiter will be used. The load limiter will switch after a defined time from stage 1 to stage 2. The shoulder belt force will not exceed a maximum force of about 4,5 kN for stage 1 and 2,5 kN for stage 2.

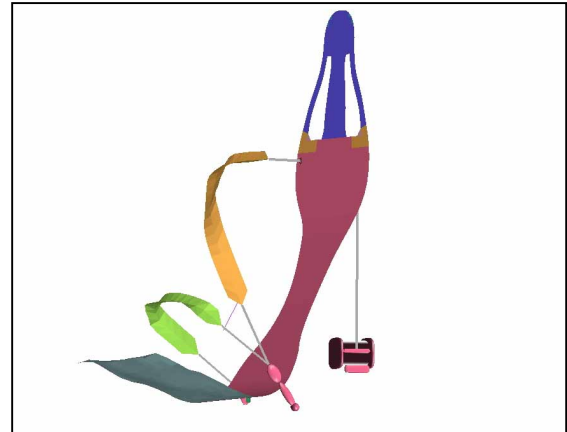


Figure 23. Driver seat belt system.

Furthermore, optimal connection points of the seat belt system with the vehicle frame were found by the simulation. The value of chest deflection is influenced by the seat belt geometry. This geometry is determined by the connection points of the d-ring with the vehicle frame and the seat belt guiding on the seat rest.

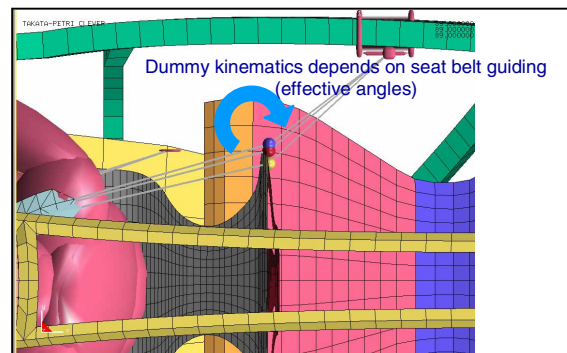


Figure 24. Seat belt guiding by the seat.

The retractor has to be connected with the vehicle frame because of the high level of the reacting forces.

For checking the seat characteristic for the case that the seat belt system is mounted on the seat, a static force load of about 2 kN was directed on the connection points at the seat rest. The results of the numerical simulation showed that the seat collapsed and, in result, the protection of the occupants could not be guaranteed. The calculation was made twice, at first with a steel seat with a thickness of 5 mm, second by a steel seat with a thickness of about 10 mm.

Please remind, the real value of the belt forces at the shoulder are from 2,5 kN up to 5 kN.

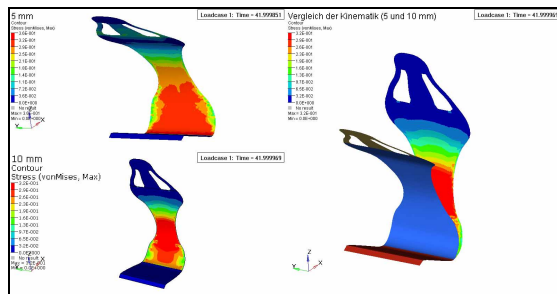



Figure 25. Seat characteristic under force influence in x-direction.

Passenger Restraint System

For the passenger side, the requirements could not be met for a system with stiff seat rest. The decision was to design a deformable seat rest. The thickness and the material characteristics were defined based on validation tests.

Table 2:
Calculated results for the CLEVER passenger

		Limits 50% HII CLEVER- Requirements 2003	18.02.2005 Passenger 50% HII	18.02.2005 Passenger 50% HII
EuroNCAP -Criteria- 50% HII			CLEVER Plus Final	CLEVER Plus Final
Simulation	seat rest	-	stiff	deformable
	Airbag	-	-	-
	AOE	-	-	-
	Steering column	-	-	-
Head	HIC ₃₆	883	7743	548
	HIC ₁₅	-	-	-
	a _{3ms} [g]	83	218	64
	-	-	-	-
Neck	My+ (max. Flexion) [Nm]	-	-	-
	My- (max. Extension) [Nm]	52	113	53
	Fx+/- (max. Shearforce) [kN]	2,7	3,9	1,4
	Fz+ (max. Force) [kN]	3,1	-3,7	0,0
	Fz- (max. Force) [kN]	3,1	1,0	3,3
	-	-	-	-
Thorax	a _{3ms} [g]	-	80	59
	a _{max} [g]	-	-	-
	s _{max} [mm]	41	36	44
	VC [m/s]	0,83	0,31	0,32
Pelvis	a _{3ms} [g]	-	111	113
Femur	Fz left [kN]	7,3	5,6	5,7
	Fz right [kN]	7,3	5,5	5,6

The passenger restraint system basically consists of a seat belt system. In addition, a head protection bolster is integrated. The front seat is designed with a deformable head rest. After the passenger's head hits the head rest of the front seat, energy will be absorbed by the deformation of the bolster and by the deformation of the head rest, too.

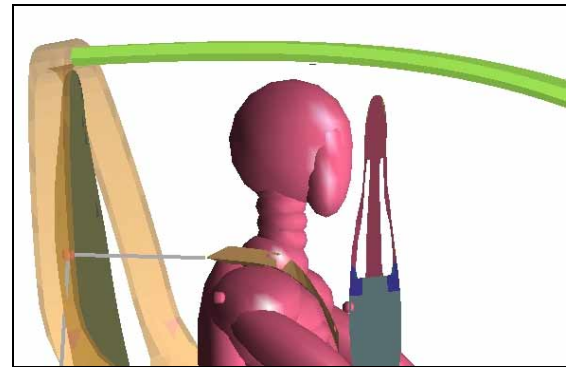


Figure 26. Position of contact between passenger head and seat rest.

The validation of the head to seat contact will be made by head impactor tests. Therefore, a head impactor with a mass of about 4,8 kg will be shot with a defined velocity of 5,3 m/s on the head rest, similar to the head impacting velocity of the CLEVER passenger. The accelerations will be measured and different bolster thicknesses have to be checked.

The expected bolster thickness by the calculated head impacting velocity is of about 20 to 50 mm, depending on the deformation characteristics and the stiffness of the seat rest.

The best performance - lowest head impactor acceleration by acceptable deformation of the back rest and a realisable thickness of the bolster – will found with the described test procedure and be used for the CLEVER vehicle.

The seat belt system is similar to the seat belt system for the driver. The time, when the load limiter switches from level 1 to level 2, is different.

CONCLUSIONS

CLEVER is an alternative vehicle concept, which is characterised by innovative solutions such as its fuel concept, the propulsion system, or the safety concept.

The safety concept is specially designed for real world accident scenarios. The advantages and disadvantages of conventional protection systems for two-wheeled and three-wheeled vehicles could be identified.

With the support of numerical simulation, the entire restraint system could be optimised. The exact application of different components was done.

The performance has to be verified by real crash tests.

To improve the safety level of two-wheel and three-wheel vehicles, occupants should be prevented from ejection during an accident. This will be realised by using a seat belt system.

It is possible to develop a small three-wheel vehicle with an occupant safety level comparable with conventional cars. The calculated values for the

assessment criteria are equal or below the defined limits of the CLEVER-CAP, which was developed specifically for CLEVER.

Furthermore, it is possible to adapt conventionally used restraint system components to alternative vehicles. A few changes have to be made, e.g. belt load limits, or the time to fire.

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